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APPLICATION OF THE VIDEO HEAD IMPULSE TEST TO DETECT VERTICAL SEMICIRCULAR CANAL DYSFUNCTION

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CONFLICTS OF INTEREST AND SOURCE OF FUNDING

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Short title

VIDEO HEAD IMPULSE TEST FOR VERTICAL CANAL DYSFUNCTION

**APPLICATION OF THE VIDEO HEAD IMPULSE TEST TO DETECT VERTICAL
SEMICIRCULAR CANAL DYSFUNCTION**

Abstract

Objective: The video head impulse test (vHIT) is a useful clinical tool to detect semicircular canal dysfunction. However, so far vHIT has been limited to measurement of the function of the horizontal semicircular canals. The goal of this study was to determine if vHIT can detect vertical semicircular canal dysfunction.

Study Design: Horizontal and vertical eye movements were recorded in response to abrupt, passive, unpredictable head turns (head impulses) in the planes of the vertical semicircular canals by high speed video (250Hz sampling rate) together with measures of the head movement. Head impulses were delivered diagonally in the plane of the vertical semicircular canals while gaze was directed along the same plane. Patients with known vestibular loss as shown by prior scleral search coil recording were tested to identify if the vHIT testing could detect the loss.

Results: The results of patients with unilateral, bilateral and individual semicircular canal dysfunction were compared to the results of a healthy control subject. The patient with bilateral vestibular loss had no compensatory slow eye movements in any direction. The patient with unilateral vestibular loss showed reduced response for head impulses activating the canals in their affected right ear (right anterior, right posterior and right horizontal head impulses). The patient with isolated canal loss showed reduced response for head impulses activating the affected right posterior canal.

Conclusions: vHIT detects peripheral deficits of both vertical and horizontal semicircular canal function and is a new tool for measuring dysfunction of individual semicircular canals in vestibular patients.

KEYWORDS: vestibular, clinical vestibular testing, semicircular canal, head impulse test, video

Introduction

A new video procedure (the video head impulse test - vHIT) which measures the eye movement response to brief, unpredictable, passive, head rotations (which we call a head impulse) has been demonstrated to be a simple valid clinical tool for testing the function of the horizontal semicircular canals (1-3). This same head impulse paradigm can be used for testing the function of the vertical semicircular canals by delivering head movements in the planes of the vertical semicircular canals and measuring the eye movements with scleral search coils (4-8), but search coils are not clinically practical, whereas vHIT is. This study set out to test if vHIT can be used to identify vertical canal function, measuring vertical eye movement responses to pitch head movements.

The vertical canals lie in planes approximately 45 deg to the sagittal plane of the head and each vertical canal is approximately parallel to the antagonistic canal on the other side of the head (9, 10). It is possible to test vertical canal function by moving the head of the patient in a diagonal plane, but this turns out to be difficult for the operator and uncomfortable for the patient. A better way of delivering head impulses in the planes of the vertical canals is to use a simple head turned position (11): the patient is seated with head and body facing the target on the wall at a distance of about 1 meter. The clinician then turns the patient's head on body about 35 deg to the left or right – whilst their gaze remains on the target and aligned with the patient's sagittal plane (Fig. 1). The clinician then pitches the patient's head up or down in the sagittal plane of the body and in this way maximally stimulates the vertical semicircular canals. The angular extent of the head rotations is small (about 10-20 degrees), so the risk of neck injury is very small.

The planes of head rotation are the left anterior- right posterior (LARP) and the right anterior left posterior (RALP) (Fig. 1). So the question to address here is: if the head rotations are delivered in the planes of the vertical canals – LARP and RALP, can vHIT detect any deficits? The strategy to answer this question was to test patients with a variety of conditions affecting the vertical canals (bilateral loss, complete unilateral loss, isolated loss of a single vertical canal) to determine if the results from vHIT could correctly identify the loss.

INSERT FIG 1 about here

The direction of the head turn determines which canal of the pair is activated. Consider stimuli for the LARP pair - pitch down activates the left anterior canal whereas pitch up activates the right posterior canal. A similar case applies for RALPs. In this way it is possible to selectively activate every one of the six canals.

Predictions:

- Healthy subjects should show normal responses for stimuli in all canal planes.
- Complete bilateral loss should result in loss of all vertical canal responses, as well as loss of horizontal canal responses.
- Complete loss of unilateral function (e.g. on the right side) should cause reduced or absent responses for right anterior and right posterior head impulses, leaving the vertical

canal responses from the left side little affected. In these patients the horizontal canal on the affected side should also have reduced or absent function.

- Isolated loss of one semicircular canal (e.g. the right posterior canal) should result in reduced right posterior canal responses, but right anterior and right lateral canal responses and the responses of all canals on the other side should be unaffected.

In this “proof of concept” study, the results from 4 typical subjects are reported. The subjects were selected as having well-defined vestibular losses as shown by prior testing with scleral search coils in our clinic. The objective of this study was to determine if vHIT could correctly detect their previously identified vestibular loss.

SUBJECTS and Methods

Subjects

Written informed consent was obtained from all subjects. The protocol was approved by the Sydney South West Area Health Service Ethics Committee (No. X06-0229, PI G. Michael Halmagyi) in accordance with the Declaration of Helsinki. Eligible patients were recruited at the Hearing and Balance Clinic, Royal Prince Alfred Hospital, Sydney, Australia. In this study only a small number of specially selected patients were used – those whose semicircular canal function had been definitely identified by prior search coil recording.

Experimental procedure. The Methods have been published in detail (1) and the following is a brief summary. Subjects and patients were instructed to fixate a laser dot on a screen at about 1 meter distance in a dimly lit room. For testing each semicircular canal, about 20 head impulses in each direction were manually delivered by the experimenter with unpredictable timing and direction. Peak head velocity of the impulses ranged from 50 to 250°/s (acceleration 750-5000°/s², amplitude 5-20°). The position of the right eye was recorded at 250Hz sampling rate using video-oculography.

Vertical head impulses were delivered by the clinician in the following manner: The patient was seated so that their body faced the target on the wall but with their head turned to be positioned about 35° to the left for testing in the RALP plane or 35° to the right for testing the LARP plane. This ensured that the target vertical canals were close to the plane of head rotation and would be maximally stimulated by the head pitch stimuli in the respective plane. The clinician placed one hand on top of the head, the other beneath the chin. The head was moved through a small angle (about 10-20 degrees) but abruptly with unpredictable direction and timing. The head movements were aimed to move the skull rather than the skin. Slippage of the skin moves the goggles relative to the eye and so causes the appearance of an eye movement. Head impulses in the horizontal plane were also recorded for comparison.

Video-oculography

The eye movement responses to head impulses were recorded using 2 dimensional recordings (horizontal and vertical) with specially-designed, lightweight high-speed video goggles as described previously (1, 2). The small mass (~60g) and tight fit of the goggles ensured minimal slippage relative to the head during the head movements, as demonstrated by the closely similar results in our previous study, when direct comparison of vHIT and search coils on the same eye were carried out (1). A digital video camera (Firefly MV, Point Grey Research Inc., Vancouver, BC) mounted on the goggles measured right eye position at 250Hz. The image of the eye was

reflected from a hot mirror to the camera. The eye was illuminated by two infrared light emitting diodes (TSUS502, Vishay Intertechnology, Malvern, PA) that could be adjusted to optimize illumination of the eye in eccentric position. Head velocity was measured by three orthogonal mini gyroscopes (IDG-300 InvenSense, Santa Clara, CA) on the goggles that were approximately aligned to the respective canal planes (horizontal, 45° LARP and 45 ° RALP plane). Eye position was calibrated with two head-fixed laser dots before recording of each canal plane. For the vertical planes, the dots were separated 15° vertically at 35° left or 35° right gaze, for the horizontal plane, the dots were separated 15° horizontally.

Data analysis

Eye position was calculated using a pupil detection method based on a center-of-gravity algorithm written in LabVIEW (National Instruments, Austin, TX). Eye position was differentiated with a two point differentiator and low pass filtered (0-30Hz bandwidth) to obtain eye velocity. Head impulses were automatically selected and aligned to peak head acceleration with custom software written in LabVIEW. Trials with blinks and outliers were automatically excluded based on an envelope around the expected eye velocity response. There are many possible ways of calculating the index of vestibular performance and the most widely used is the gain of the vestibulo-ocular reflex (VOR) where the gain is given by eye velocity divided by head velocity. We present here VOR gains which correspond to this method. A VOR deficit was defined as a vHIT gain of less than 0.68 (1). The data analysis program also identified overt and covert saccades and they are shown as red traces in the results records.

Results

The results for a healthy subject are shown in Fig. 2. The plots show superimposed records of de-saccaded eye velocity responses (blue traces) to head velocity stimuli (green traces) for about 20 brief unpredictable head rotations in each plane. Eye velocity has been inverted in these figures to allow easy comparison of eye velocity and head velocity. In a healthy subject the eye velocity matches head velocity so the head velocity traces and eye velocity traces are almost exactly superimposed in every plane. All gain values of the vestibulo-ocular reflex (VOR) are in the normal range. In contrast, the results for the patient with idiopathic bilateral vestibular loss (Fig. 3) show absent eye velocity response for every direction of head rotation, including all vertical canals. To compensate for the vestibular deficit, multiple catch-up saccades appear at the end of head rotation to every direction (red traces).

Insert Fig 2 and Fig 3 normal and BVL

The results for the patient with right complete unilateral vestibular loss after surgery for a vestibular Schwannoma (Fig. 4) show that eye velocity matches head velocity reasonably well for leftward head rotations (towards the healthy ear), but not for rightwards head rotations (towards the affected ear). As is the case for the horizontal canal, reduced or absent slow phase eye velocity appears during head turns towards the right anterior and posterior canals. The slow phase eye velocity is inadequate in response to stimulation of each canal on the affected side. The numerical VOR gain values show the clearly reduced gain for rotations towards the affected side. For the responses towards the affected ear not only is the slow phase eye velocity

insufficient, but there are many overt saccades (red traces) which occur after the head impulse (12).

Insert Fig 4 RUVD

Fig. 5 shows the results for a patient with a known idiopathic, isolated loss of the right posterior canal (as shown by previous scleral search coil testing). The responses in all the canals were normal, with the exception of the test of the single affected canal – the right posterior canal. Here the eye velocity response was not adequate and there were covert saccades (red traces) during the head impulses for just this canal. The vHIT procedure correctly identified this patient's deficit in the affected posterior canal and clearly detected the corrective covert saccades. The VOR gain for this canal is significantly below normal, whereas the VOR gains for all the other canals are in the normal range.

Insert Fig 5 RPCD

DISCUSSION

When applied to testing vertical canals vHIT correctly identified the canal function in a normal subject, a patient with bilateral vestibular loss, a patient with unilateral vestibular loss and also a patient with isolated loss of canal function in one vertical canal. The result for the patient with the isolated canal loss (as identified by previous scleral search coil testing) is the most definitive evidence in support of the specificity of the vHIT tests of the vertical canals. These results provide a “proof of concept” by showing that vHIT is a clinically practical way of assessing the function of all six semicircular canals. Clearly now that the concept has been proven, large sample sizes are needed to establish the population parameters.

Modifying the examination technique using the “head turned” testing protocol as here with the patient fixating an eccentric target in the plane of the vertical canals tested (Fig. 1) has a significant advantage: the elicited eye movements are mainly vertical and can be measured with two dimensional video-oculography without the need of complicated three dimensional analysis, which would require the measurement of ocular torsion (11).

In contrast to horizontal head impulses, vertical head impulses are more difficult to apply consistently in the plane of the respective vertical canal due to limited neck mobility. In addition, eccentric eye position and limited vertical range by the upper and lower eyelid make pupil tracking with video technically more demanding. These limitations mean that in testing vertical canals with vHIT, it is not usually possible to obtain a peak head velocity as large as that delivered in the plane of the horizontal canals. Future studies will be needed to verify the general applicability of this technique to a large population.

CONCLUSION

Testing of vertical semicircular canals is practical with vHIT. The technique is capable of detecting dysfunction of individual vertical semicircular canals. In contrast to scleral search coils, the only alternative to date, the new method is non-invasive and applicable in clinics.

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FIGURE Legends

FIG. 1. The head movements for LARP (left anterior – right posterior) and RALP (right anterior – left posterior) and lateral semicircular canal stimulation (arrows), as viewed from the fixation point. For testing the vertical canals, the person's head is turned as shown and the movement of the head is a pitch movement in the plane of the named canals as represented by the vertical arrows. For testing horizontal canals, the movement is in the plane of the horizontal canals as shown. These images are modified from the free educational iPhone or iPad app called 'aVOR', developed by the first author and available on iTunes.

FIG. 2. The records here show that for a healthy subject the head velocity traces and eye velocity traces are almost superimposed for the direction of each semicircular canal. The VOR gain values for head turns in every canal plane are in the normal range (1). The plots themselves in this and the following figures are time series showing superimposed records of the head velocity stimulus (green traces) and the slow phase eye velocity responses (blue traces) to about 20 brief unpredictable head turns in the direction of each semicircular canal. In these figures eye velocity has been inverted to allow easy comparison of eye velocity and head velocity, and both leftwards and rightwards head movements are shown as positive. The VOR gain value is shown next to each group of responses. Overt or covert saccades are shown as red traces (12). The inset at the centre shows the rotation axes of the semicircular canals being tested.

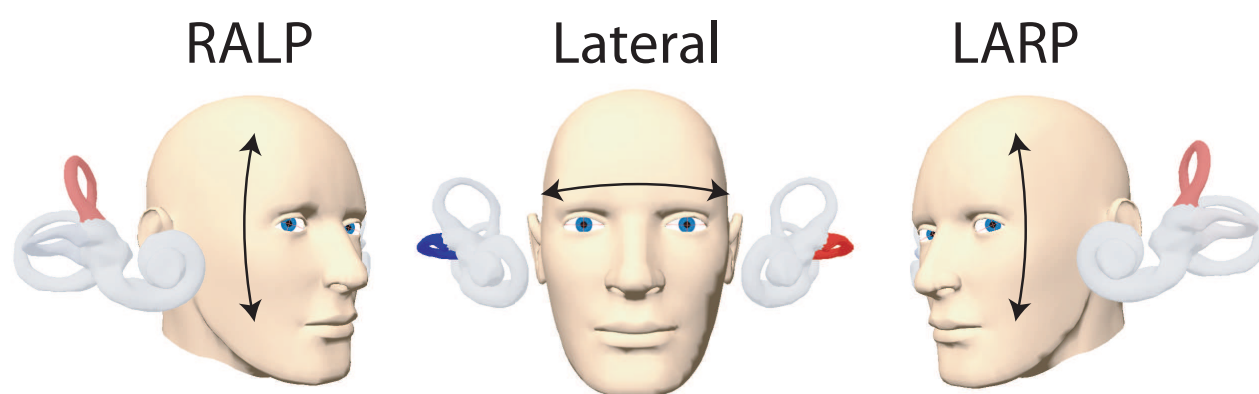
FIG. 3. Results for a patient with idiopathic bilateral vestibular loss. For every direction of head rotation (green traces), there is no effective compensatory slow phase eye velocity response (blue traces). There is a shower of saccades at the end of each head rotation (red traces). The VOR gains for all planes are very low, but mostly above zero. From our previous comparisons with simultaneous data from scleral search coils and video (1), we know that the small eye deviations around peak head acceleration (arrows), which raise the gain values, are artifactual and probably due to very small goggles slippage. They only appear salient here, because the VOR gains are low. In normal subjects (e.g. Figure 2), the artifacts remain concealed within the VOR response.

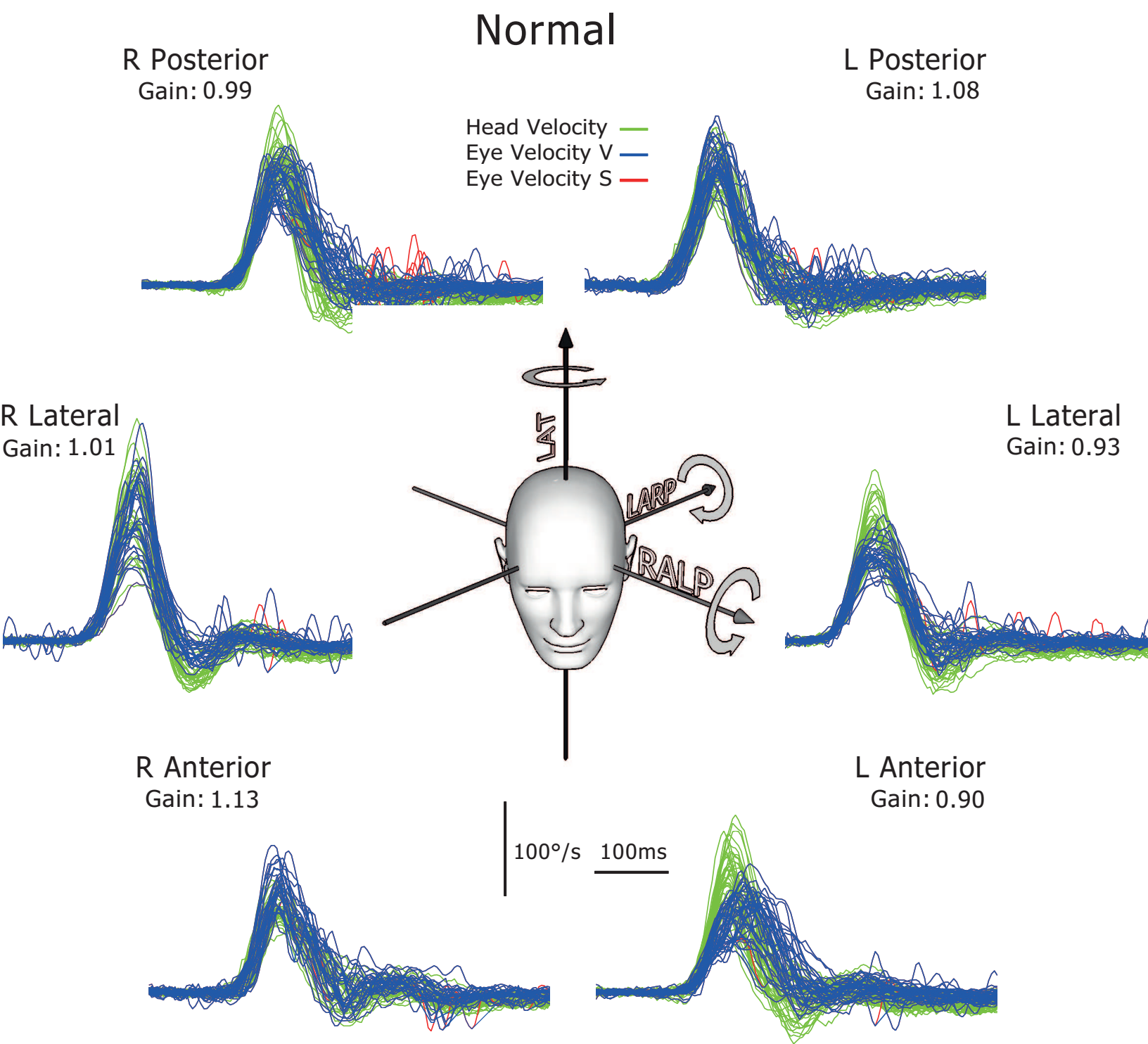
FIG. 4. Results for a patient with right unilateral vestibular loss after surgery for a vestibular Schwannoma. For every rotation direction activating canals on the healthy left side, the eye velocity response is around normal. However, for every rotation direction activating canals on the affected right side, there is a reduced or absent VOR response. In particular, the vertical canals on the affected side have a clearly reduced function. To compensate for the deficit on the affected right side, overt saccades appear after head rotation (red traces).

FIG. 5. Results for a patient with a known idiopathic, isolated loss of the right posterior canal, as shown by prior testing using scleral search coils. For rotations which would activate this single canal, there is a clear reduction of eye velocity (blue traces) during the head velocity stimulus (green traces), quickly followed by covert saccades (red traces). The responses for all other canals was in the normal range.

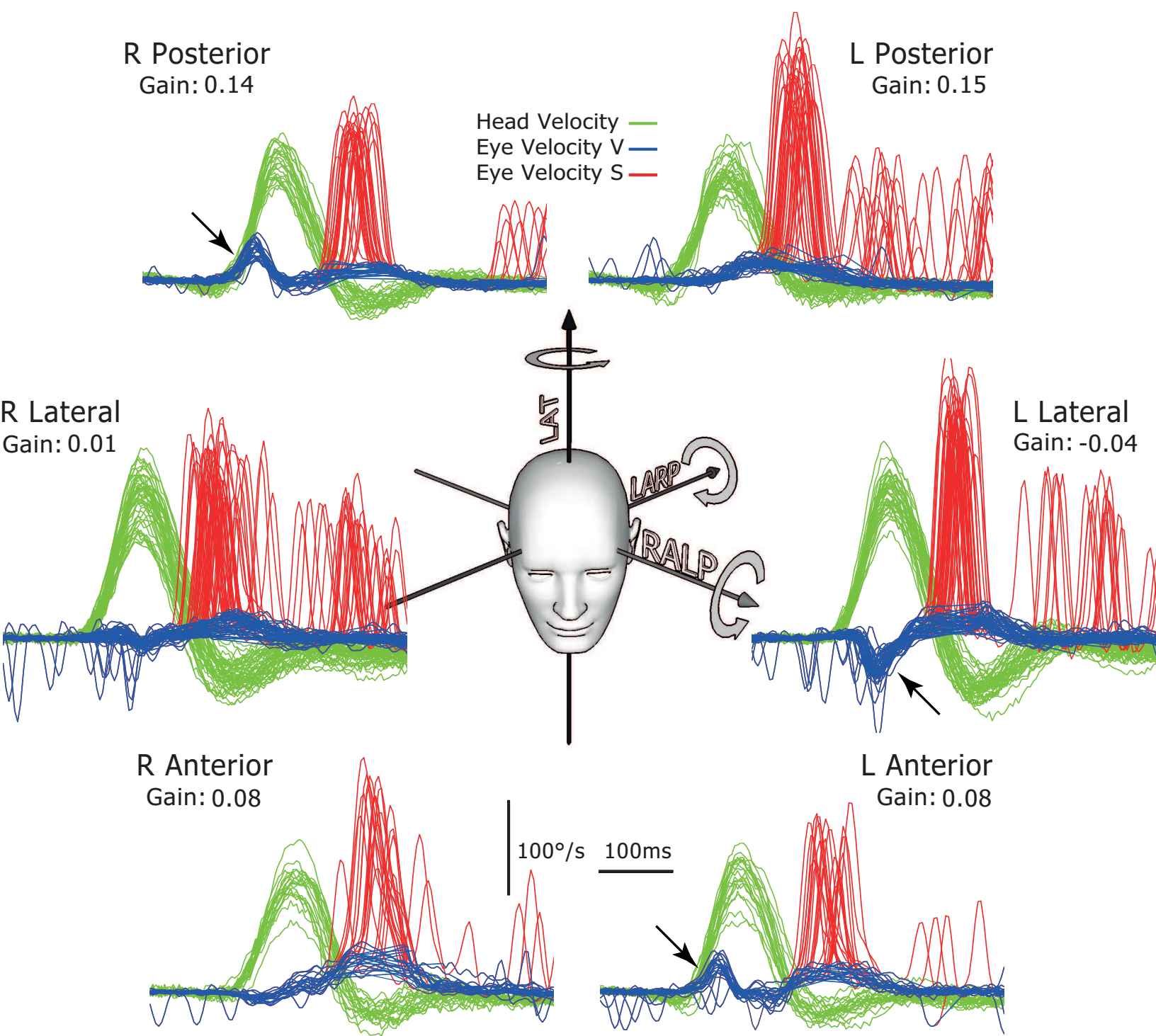
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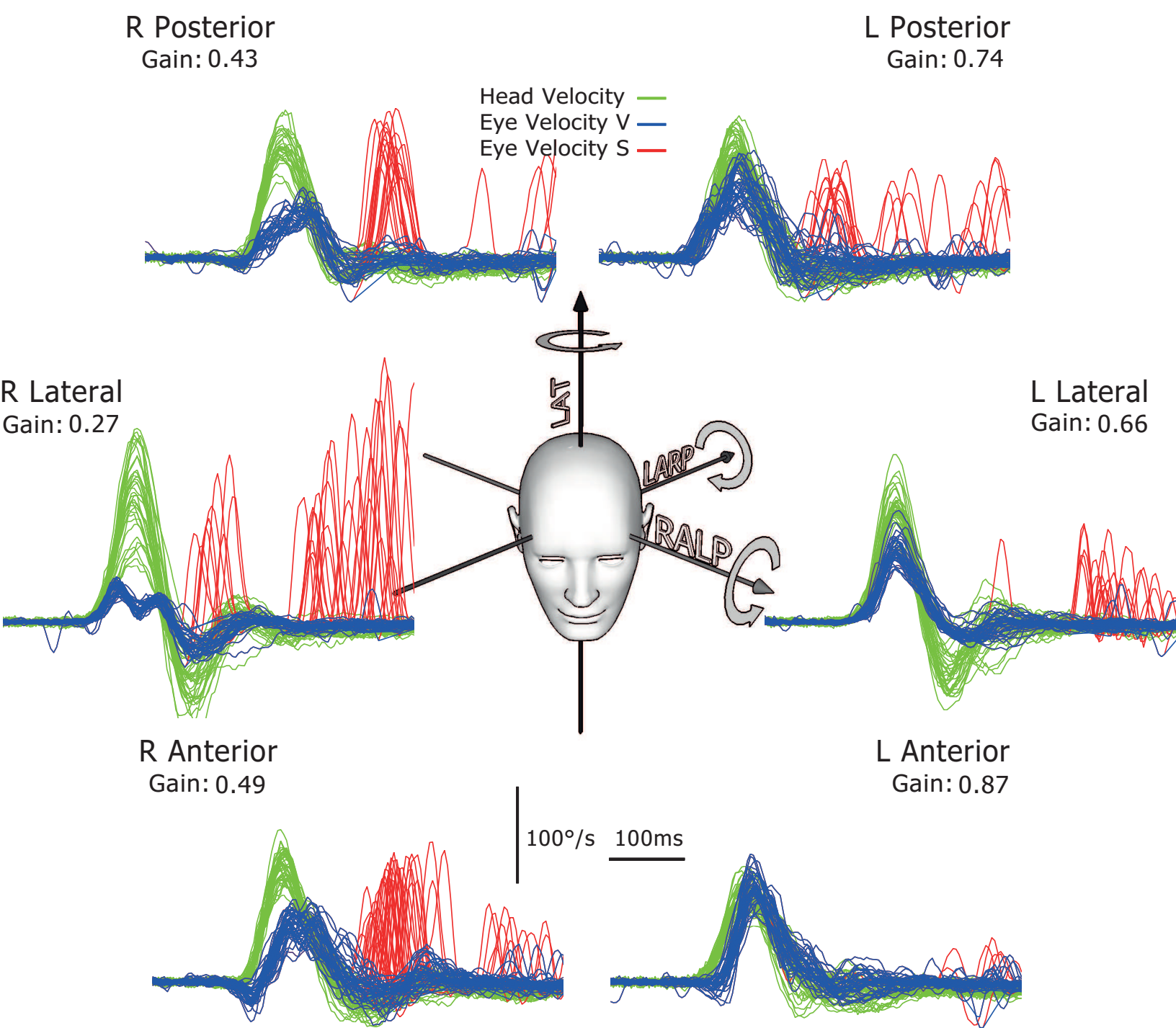




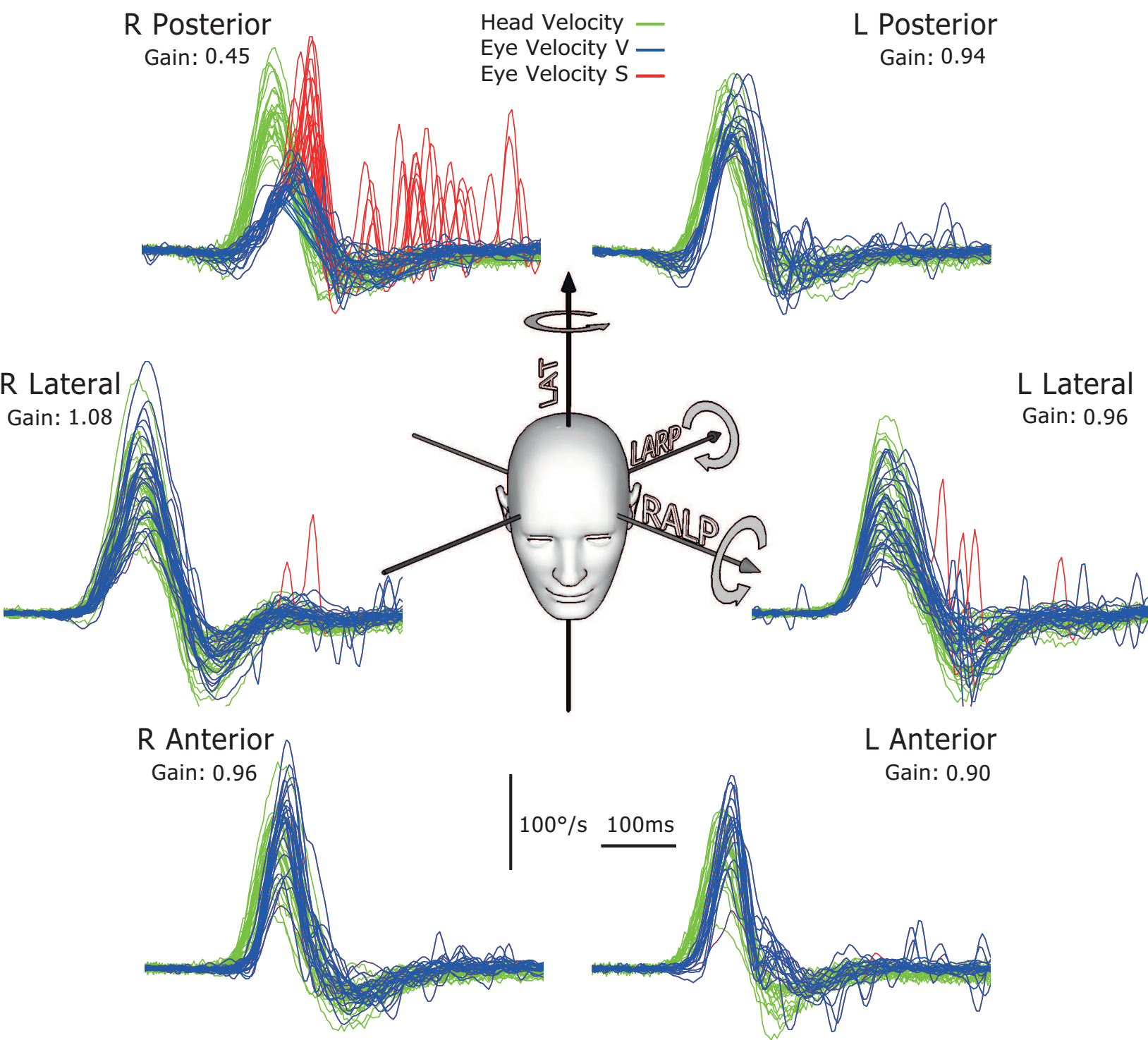
Bilateral Vestibular Loss



Right Unilateral Vestibular Loss



Isolated Right Posterior Canal Loss



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